

DIFFERENTIALLY ACTUATED MICROACTUATOR

Cross Reference to Related Application

This application claims the benefit of U.S. Provisional Application no. 60/416,479 filed October 7, 2002, the entire contents of which are hereby expressly incorporated by reference.

Field of the Invention

This invention is directed to differential actuation of one or more piezoelectric transducer (PZT) motors on a disk drive head suspension.

Background of the Invention

Conventionally, PZT motors have a generally planar configuration, with one or two opposing major faces plated or otherwise coated with a conductive material, such as gold. Conventionally, it has been known to ground one face of the PZT and electrically energize the other face to actuate the PZT. Applying one polarity of voltage causes the PZT to contract in a direction parallel to the faces having electrodes, while applying the other polarity causes the PZT to expand in a direction parallel to the plane of the opposing major faces having the electrodes. It is to be understood that, while the PZT is expanding in the direction parallel to the plane of the opposing major faces, it is correspondingly contracting in a perpendicular direction, and conversely, when the PZT is contracting in the direction parallel to the plane of the opposing major faces, it is correspondingly expanding in the perpendicular direction. The present invention preferably makes use of the movement (of expansion or contraction) in the direction parallel to the plane of the opposing major faces carrying electrodes, while accommodating or "tolerating" the movement perpendicular thereto.

Brief Description of the Drawings

Figure 1 is a top plan view of the suspension assembly showing a pair of PZT motors.

Figure 2 is a bottom plan view of the suspension assembly of Figure 1.

Figure 3 is an enlarged fragmentary view of the top of the suspension assembly from Figure 1, showing details of the PZT motors and the top electrical connections thereto.

Figure 3a is an enlarged fragmentary plan view of the bottom of the suspension assembly of Figure 1.

Figure 4 is a section view along line A-A of Figure 3.

Figure 4a is an exploded view of the suspension assembly of Figure 1.

Figure 4b is a perspective view of suspension assembly of Figure 1 from a first side.

Figure 4c is a perspective view of the suspension assembly of Figure 1 from a second side opposite the first side shown in Figure 4b.

Figure 4d is a top plan view of a first version of a first alternative embodiment wherein the PZT motors are ultrasonically bonded to extensions of the conductive leads formed from the flexure material.

Figure 4e is a bottom plan view of the version shown in Figure 4d.

Figure 4f is a composite view of Figures 4d and 4e with hidden lines shown for clarity.

Figure 4g is a section view along line I-I of Figure 4f.

Figure 4h is a section view along line II-II of Figure 4f.

Figure 4i is a top plan view of a second version of the first alternative embodiment wherein ultrasonic bonding using a pair of extra pieces electrically attach the PZT motors to the conductive leads formed from the flexure material.

Figure 4j is a bottom plan view of the version shown in Figure 4i.

Figure 4k is a composite view of Figures 4i and 4j with hidden lines shown for clarity.

Figure 4l is a section view along line I-I of Figure 4k.

Figure 4m is a section view along line II-II of Figure 4k.

Figure 4n is a top plan view of a third version of the first alternative embodiment wherein the PZT motors are attached using solder or conductive epoxy to extensions of the conductive leads formed from the flexure material.

Figure 4o is a bottom plan view of the version shown in Figure 4n.

Figure 4p is a composite view of Figures 4n and 4o with hidden lines shown for clarity.

Figure 4q is a section view along line I-I of Figure 4p.

Figure 4r is a section view along line II-II of Figure 4p.

Figure 4s is a top plan view of a fourth version of a first alternative embodiment wherein solder or conductive epoxy connections using a pair of extra pieces electrically attach the PZT motors to the conductive leads formed from the flexure material.

Figure 4t is a bottom plan view of the version shown in Figure 4s.

Figure 4u is a composite view of Figures 4s and 4t with hidden lines shown for clarity.

Figure 4v is a section view along line I-I of Figure 4u.

Figure 4w is a section view along line II-II of Figure 4u.

Figure 5 shows a bottom plan view of another embodiment.

Figure 6 shows a top plan view of the embodiment of Figure 5.

Figure 7 is an enlarged fragmentary view of a portion of Figure 6 showing details of the mounting arrangement for the PZT motors in this embodiment.

Figure 8 is a section view taken along line 8-8 of Figure 7.

Figure 8a is an exploded view of the suspension assembly of this embodiment.

Figure 8b is a perspective view of the suspension assembly of this embodiment.

Figure 8c is an exploded perspective view of the PZT motors, wire, and conductive trace layer showing details of the conductive pads for electrically powering the PZT motors.

Figure 8d is an enlarged plan view of a portion of the conductive trace layer of Figure 8c showing a layout for a wire bond pad used to connect to a first surface of

the PZT motors and a plurality of trace pads used to connect to a second surface of the PZT motors.

Figure 8e is a top plan view of a first version of a second alternative embodiment wherein the PZT motors are ultrasonically bonded to extensions of the conductive leads formed from the flexure material.

Figure 8f is a bottom plan view of the version shown in Figure 8e.

Figure 8g is a composite view of Figures 8e and 8f with hidden lines shown for clarity.

Figure 8h is a section view along line I-I of Figure 8g.

Figure 8i is a section view along line II-II of Figure 8g.

Figure 8j is a top plan view of a second version of the second alternative embodiment wherein ultrasonic bonding using a separate piece to electrically attach one side of the PZT motors to the conductive leads formed from the flexure material.

Figure 8k is a bottom plan view of the version shown in Figure 8j.

Figure 8kk is a plan view of the trace layer for the version shown in Figure 8k.

Figure 8kkk is a plan view of the substrate layer for the version shown in Figure 8k.

Figure 8kkkk is a plan view of the dielectric layer for the version shown in Figure 8k.

Figure 8l is a composite view of Figures 8j and 8k with hidden lines shown for clarity.

Figure 8m is a section view along line I-I of Figure 8l.

Figure 8n is a section view along line II-II of Figure 8l.

Figure 8nn is a plan view of the separate piece used in the version shown in Figure 8k.

Figure 8nnn is an exploded view of the various layers of the separate piece shown in Figure 8nn.

Figure 8o is a top plan view of a third version of the second alternative embodiment wherein the PZT motors are attached using solder or conductive epoxy to extensions of the conductive leads formed from the flexure material.

Figure 8p is a bottom plan view of the version shown in Figure 8o.

Figure 8q is a composite view of Figures 8o and 8p with hidden lines shown for clarity.

Figure 8r is a section view along line I-I of Figure 8q.

Figure 8s is a section view along line II-II of Figure 8q.

Figure 8t is a top plan view of a fourth version of the second alternative embodiment wherein solder or conductive epoxy connections using a pair of extra pieces electrically attach the PZT motors to the conductive leads formed from the flexure material.

Figure 8u is a bottom plan view of the version shown in Figure 8t.

Figure 8v is a composite view of Figures 8t and 8u with hidden lines shown for clarity.

Figure 8w is a section view along line I-I of Figure 8v.

Figure 8x is a section view along line II-II of Figure 8v.

Figure 8xx shows an exploded and composite view of the separate piece shown in Figure 8u.

Figure 9 shows a top plan view of a third embodiment.

Figure 10 is bottom plan view of the embodiment of Figure 9.

Figure 11 is an enlarged fragmentary view of a portion of Figure 9 showing details of the mounting arrangement for the PZT motors in this embodiment.

Figure 12 is a still further enlarged section view taken along line 12-12 of Figure 11.

Figure 12a is an exploded perspective view of the suspension assembly of Figure 9.

Figure 12b is a perspective view of the suspension assembly of Figure 9.

Figure 12c is a top plan view of a first version of a third alternative embodiment wherein the PZT motors are ultrasonically bonded to extensions of the conductive leads formed from the flexure material.

Figure 12d is a bottom plan view of the version shown in Figure 12c.

Figure 12e is a composite view of Figures 12c and 12d with hidden lines shown for clarity.

Figure 12f is a section view along line I-I of Figure 12e.

Figure 12g is a section view along line II-II of Figure 12e.

Figure 12h is a top plan view of a second version of the third alternative embodiment using ultrasonic bonding of a separate piece to electrically attach one side of the PZT motors to the conductive leads formed from the flexure material.

Figure 12i is a bottom plan view of the version shown in Figure 12h.

Figure 12j is a composite view of Figures 12h and 12i with hidden lines shown for clarity.

Figure 12k is a section view along line I-I of Figure 12j.

Figure 12kk is an enlarged plan view of the separate piece useful in the practice of the version shown in Figure 12h.

Figure 12kkk is an exploded view of the layers making up the separate piece of Figure 12kk.

Figure 12l is a section view along line II-II of Figure 12j.

Figure 12m is a top plan view of a third version of the third alternative embodiment wherein one side of the PZT motors is attached using solder or conductive epoxy to an extension of the conductive leads formed from the flexure material and the other side of the PZTs is bonded to conductive pads in the conductive trace layer of the flexure.

Figure 12n is a bottom plan view of the version shown in Figure 12m.

Figure 12o is a composite view of Figures 12m and 12n with hidden lines shown for clarity.

Figure 12p is a section view along line I-I of Figure 12o.

Figure 12q is a section view along line II-II of Figure 12o.

Figure 12r is a top plan view of a fourth version of the third alternative embodiment wherein solder or epoxy connection is used with a separate piece to electrically attach the PZT motors to the conductive leads formed from the flexure material.

Figure 12s is a bottom plan view of the version shown in Figure 12r.

Figure 12t is a composite view of Figures 12r and 12s with hidden lines shown for clarity.

Figure 12u is a section view along line I-I of Figure 12t.

Figure 12v is a section view along line II-II of Figure 12t.

Figure 13 shows a top plan view of a fourth embodiment having a prefabricated motor subassembly.

Figure 14 shows a bottom plan view of the embodiment of Figure 13.

Figure 15 is an enlarged fragmentary view of a portion of Figure 13.

Figure 16 is an enlarged section view taken along line 16-16 of Figure 15.

Figure 17 shows an exploded view of the prefabricated motor subassembly and head suspension assembly of which it forms a part.

Figure 18 shows a perspective assembly view of the embodiment of Figure 17.

Figure 18a is a top plan view of a first version of a fourth alternative embodiment wherein the PZT motors in a prefabricated subassembly are ultrasonically bonded to extensions of the conductive leads formed from the flexure material.

Figure 18b is a bottom plan view of the version shown in Figure 18a.

Figure 18c is a composite view of Figures 18a and 18b with hidden lines shown for clarity.

Figure 18cc is an enlarged plan view of a motor subassembly metal substrate from Figure 18a.

Figure 18ccc is a plan view of a dielectric layer for the motor subassembly of Figure 18a.

Figure 18cccc is a plan view of a conductive pad layer for the motor subassembly of Figure 18a.

Figure 18d is a section view along line I-I of Figure 18c.

Figure 18dd is an enlarged plan view of a composite or wireform drawing (with hidden lines shown for clarity) of the metal substrate of Figure 18cc, together

with the dielectric layer of Figure 18ccc and the conductive pad layer of Figure 18cccc.

Figure 18ddd is an enlarged plan view similar to that of Figure 18dd, except showing the lead extensions and a portion of the dielectric layer from the flexure.

Figure 18e is a section view along line II-II of Figure 18c.

Figure 18f is a top plan view of a second version of the fourth alternative embodiment wherein ultrasonic bonding using a pair of extra pieces electrically attach the PZT motors to the conductive leads formed from the flexure material.

Figure 18g is a bottom plan view of the version shown in Figure 18f.

Figure 18h is a composite view of Figures 18f and 18g with hidden lines shown for clarity.

Figure 18hh is an enlarged composite or wireform view (with hidden lines shown for clarity) of the motor subassembly of Figure 18f, together with the separate pieces of laminate connecting the motor subassembly to a portion of the flexure.

Figure 18i is a section view along line I-I of Figure 18h.

Figure 18j is a section view along line II-II of Figure 18h.

Figure 18k is a top plan view of a third version of the fourth alternative embodiment wherein the PZT motors are attached using solder or conductive epoxy to extensions of the conductive leads formed from the flexure material.

Figure 18l is a bottom plan view of the version shown in Figure 18k.

Figure 18m is a composite view of Figures 18k and 18l with hidden lines shown for clarity.

Figure 18mm is an enlarged composite or wireform view (with hidden lines shown for clarity) of the motor subassembly of Figure 18k, together with lead extensions and solder connections between the motor subassembly and a portion of the flexure.

Figure 18n is a section view along line I-I of Figure 18m.

Figure 18o is a section view along line II-II of Figure 18m.

Figure 18p is a top plan view of a fourth version of the fourth alternative embodiment wherein solder or conductive epoxy connections using a pair of extra

pieces electrically attach the PZT motors to the conductive leads formed from the flexure material.

Figure 18q is a bottom plan view of the version shown in Figure 18p.

Figure 18r is a composite view of Figures 18p and 18q with hidden lines shown for clarity.

Figure 18rr is an enlarged composite or wireform view (with hidden lines shown for clarity) of the motor subassembly of Figure 18p together with separate pieces of laminate using solder connections between the motor subassembly and a portion of the flexure.

Figure 18s is a section view along line I-I of Figure 18r.

Figure 18t is a section view along line II-II of Figure 18r.

Detailed Description

In the practice of the present invention, the PZT is electrically isolated from what has heretofore been a grounding substrate. In this arrangement, each major face of the PZT is independently available for receiving a driving voltage, permitting the use of a unipolar voltage source to obtain both expanding and contracting modes of operation of the PZT (i.e., when either major face may be connected to circuit common or “ground”). Furthermore, this result is obtained while the primary plane of the PZT is kept parallel to the primary plane of the stainless steel load beam of the head suspension. Maintaining this parallelism greatly simplifies the attachment of the PZT to the substrate, and keeps a low profile for the overall assembly, in contrast to prior art arrangements where the PZT is not parallel to the primary plane of the load beam. It is to be understood that “unipolar voltage source” refers to a single polarity electrical voltage source wherein, for example, a positive voltage potential is applied to a first major surface of the PZT motor when measured with respect to a reference voltage potential at a second major surface of the PZT element (which is normally at a ground or “circuit common” potential). In order to obtain both the expanding and contracting modes of operation in the practice of the present invention, the second (normally the bottom) surface of each of the two PZT motors must be isolated from

any mechanical contact which would inherently “ground” those surfaces, since the unipolar source must be reconnected with reversed polarity to the PZTs to switch operation from the expanding mode to the contracting mode (or vice-versa). In contrast to a unipolar source, a bipolar source has the ability to change the polarity of the voltage supplied on its output terminal, when measured with respect to circuit common. However, bipolar sources are typically more complicated and hence more costly than unipolar sources (even with output switching of both terminals for a unipolar source) and thus there is a need for PZT loads to be able to be driven from unipolar sources. A head suspension typically includes a load beam, in which case the load beam forms a species of substrate for the present invention, which may be suitable for assemblies other than head suspensions. It is further to be understood that the metal layer forming the load beam for a head suspension may have additional portions forming a spring region and a mounting region for receiving a mounting plate.

One embodiment of this invention may be seen in Figures 1 - 4 and is a disk drive head suspension or assembly 20 which allows electrical isolation of the PZT from the ground or circuit common connection, while permitting wire bonding to the PZT at both major surfaces (top and bottom) of the PZT. Head suspension 20 includes a pair of PZT motors 22, 24. As used herein it is to be understood that the terms “top” and “bottom” are relative terms, in that typically disk drive head suspensions are employed on both sides of a disk. As such, “top” refers to the free side or major surface 26 of the PZT 22 or 24 facing away from the suspension 20 which is visible in Figure 1, and “bottom” refers to the major surface 28 of the PZT facing towards the suspension 20, partially visible in Figure 2. Figure 3a shows an enlarged plan view detail of a portion of the assembly 20 from the same side as shown in Figure 2. In an exploded view, Figure 4a shows the PZT motors 22 and 24, a first connection means 32 in the form of a top wire stitch 32a, a second connection means 34 in the form of a bottom wire stitch 34a, a stainless steel substrate 30 (here in the form of a load beam 30a, a stainless steel layer 38 for a flexure 40, a dielectric layer 42, and a layer of conductive traces 44 preferably formed of copper. The flexure 40

is made up of the stainless steel layer 38 for the flexure, the dielectric layer 42 and the copper traces 44. The connection means 32, 34 (shown in this embodiment in the form of wire stitches 32a, 34a) are for making electrical connections between the PZT motors 22, 24 and the conductive traces 44. A first aperture 46 in the load beam or substrate 30 enables the top wire stitch 32a (or first connection means 32) to be attached to a first bonding pad 56 electrically connected to one of the copper traces 44. In Figure 4a the suspension 20 includes a mounting plate 50, and the substrate 30 has a second aperture 52 and a third aperture 54 for connection to the bottom conductive surfaces of the PZTs 22 and 24. Conductive copper traces 44 have a first bonding pad 56 and a second bonding pad 58. It is to be understood that the top surfaces 26 of each of the PZT motors 22 and 24 is conductive.

It is to be understood that in the version shown in Figures 1-4c, the PZT motors 22 and 24 are electrically insulated from the stainless steel substrate/loadbeam 30 by an insulating epoxy 60 shown somewhat schematically in Figure 4a. In this embodiment, each PZT motor is mechanically, but not electrically, bonded via a bottom conductive surface 28 (i.e., the second major surface) to the substrate 30 (e.g., load beam 30a), typically made of stainless steel, using an adhesive (such as epoxy) that is filled with beads made of an insulating material. The adhesive is a type RP 672-1A (Alumina filler) or RP 672-1S (Silica filler) available from Ablestik at 20021 Susana Rd., Rancho Dominguez, California 90221. The average particle size for the alumina filler is about 1 micron up to a maximum particle size of about no more than 5 microns. No surface treatment is required for the alumina filler version of the adhesive. For the silica filler version, the surface is preferably treated with a silane adhesion promoter, and the average particle size is about 4.5 microns, with a maximum particle size of about no more than 15.5 microns. For both the silica and alumina filler type adhesives, spacers are preferably glass beads with a particle size range of about 9 to about 20 microns in diameter.

It is to be understood that the adhesive (insulating epoxy) extends over some, but not all, of the bottom surface, and electrically isolates the mechanically bonded conductive surface 28 of the PZT 22 or 24 from the ground plane of the suspension 20

formed when the substrate 30 is conductive. A pair of openings, (the second and third apertures 52, 54) in the substrate 30 aligned with the region free of adhesive permit electrical connection to the bottom conductive surface 28 of each PZT. Electrical connection to the top conductive surface 26 (i.e., the first major surface, on the non-disk side in this arrangement) of each PZT is completed (in this embodiment) using a standard ultrasonically bonded top wire stitch 32a, the structure and method of which have been utilized on prior art designs and are conventional. The electrical connection to the bottom conductive layer of the PZT is also completed with an ultrasonically bonded bottom wire stitch 34a, but is completed from the disk side of the suspension through access features (such as the second and third apertures 52 and 54 in the load beam 30a) in a region where the adhesive is absent. It is to be understood that the two PZT motors 22 and 24 have opposite polarizations with respect to each other such that when the same voltage is applied to the PZT motors using the parallel electrical connection shown, one PZT will contract and the other PZT will expand in the direction parallel to the major surfaces of the PZT motors, thus “steering” the distal end 62 of the head suspension 20 laterally in a first direction 64. It is to be further understood that by applying an oppositely poled voltage across the pair of electrically parallel connected PZTs, the distal end of the head suspension will be driven in a second direction 66 diametrically opposite the first direction 64, as shown in Figure 4b.

Referring now most particularly to Figures 3a and 4a, the second and third apertures 52 and 54 in the stainless steel load beam 30a are each aligned with one of the PZTs 22, 24 to permit electrical connection thereto. In this embodiment, the first aperture 46 (together with a mirror image aperture 48) also serves the purpose of providing a “hinge” to permit lateral movement of the distal end 62 of the load beam 30a when driven by the expansion and contraction of the PZT motors 22 and 24. Figures 4b and 4c show perspective views of the assembled version of the above described embodiment.

It is to be understood that the present invention is also applicable to an assembly having only one PZT motor. Furthermore, it is within the present invention

to use ultrasonic bonding of conductive leads formed from the flexure material as shown in Figures 4d-4h or formed from an additional add-on component as shown in Figures 4i-4m, similar in structure to the flexure to make the electrical connection to the PZT motor(s). Additionally, it is within the present invention to use conductive epoxy or solder as shown in Figures 4n-4r to attach conductive leads formed from the flexure material or from an additional add-on component similar in structure to the flexure as shown in Figures 4s-4w to make the electrical connection to the PZT motor(s).

Referring now most particularly to Figures 4d through 4h, the version using ultrasonic bonding between the PZT motors 22, 24 and extensions of the conductive leads 44 formed from the flexure 40 may be seen. It is to be understood that Figure 4f is a “composite” or wireform view of the details of Figures 4d and 4e as if the parts of the assembly 20 were transparent. In this version, leads 44 from the flexure 40 are extended as shown at 44a to overlap the PZT motors 22, 24 on the free side 26 and at 44b to overlap the opposite side 28 of the PZT motors 22, 24. Conventional ultrasonic bonding is used to mechanically and electrically secure the respective overlapping portions 44a and 44b of the leads 44 where they contact the PZTs 22, 24 to form electrical connections between the leads 44 and the PZTs 22, 24 in a manner analogous to the wire stitch version described above. The stainless steel layer 38 supports a portion of the respective lead extensions 44a and 44b, and the dielectric layer 42 insulates lead extension 44b from the substrate 30 or load beam 30a as lead extension passes over the region intermediate the second and third apertures 52 and 54, as shown in Figure 4h. The stainless steel layer 38 supports lead extension 44a (insulated by dielectric layer 42) as it passes through the first aperture 46, as shown in Figure 4g. The lead extension 44a is formed into an offset or “Z-shaped” configuration to position lead extension 44a in the plane of surface 26, as it extends from the main body portion of flexure 40, which in this embodiment, is mounted via stainless steel layer 38 on the opposite side of the load beam 30a.

Referring now to Figures 4i through 4m, a further version of the present invention may be seen. In this version, ultrasonic bonding is used with a pair of

intermediate pieces formed from a three layer laminate similar to the flexure 40. Again it is to be understood that Figure 4k is a wireform view or composite of Figures 4i and 4j. In this version, a pair of separate pieces 70, 72 connect the leads 44 with the PZT motors 22, 24. A conductor 74 in piece 70 connects to the free side 26 of the PZTs 22, 24. Similarly, a conductor 76 in piece 72 connects to the other side 28 of PZTs 22, 24. Conductors 74 and 76, formed, respectively as conductive traces 44c and 44d in the laminated pieces 70, 72 are connected, respectively, to individual leads from among the group of leads 44 in flexure 40 for powering the PZTs. An electrical connection is made through first aperture 46 to connect leads 44 to piece 70, and the conductor 76 extends through the second and third apertures 52 and 54 to provide electrical connection to side 28 of the PZTs. Ultrasonic bonding is used to form the connections mentioned with respect to this version.

Referring now to Figures 4n through 4r, a version similar to that of Figures 4d through 4h may be seen. In this version, solder or conductive epoxy connections 80 replace the ultrasonic bonding of conductors 44 of lead extensions 44a and 44b to the PZTs 22, 24.

Referring now to Figures 4s through 4w, a version similar to that of Figures 4i through 4m may be seen. In this version, solder connections 80 are used with separate pieces 70, 72 to electrically and mechanically bond conductors 44c and 44d to the PZTs 22, 24. The separate pieces 70 and 72 may be formed of a laminate of a trace layer, an insulating layer, and a support layer, similar or identical to the laminate of the flexure 40 described above.

There are also other embodiments of the innovation which allow differential actuation as follows. Referring now most particularly to Figures 5-8d, a second wire stitch type embodiment of the present invention may be seen. In this embodiment, the PZT motors 22, 24 are mounted on the disk side of the suspension 20a. Figures 5 and 6 show bottom and top plan views of this embodiment, and Figure 7 is an enlarged fragmentary view of a portion of Figure 6 showing details of the mounting arrangement and a wire or wire bond 82 and wire bond pad 84 for the PZT motors 22, 24 in this embodiment. Figure 8 is a section view taken along line 8-8 of Figure 7.

Figure 8a is an exploded view of the suspension assembly of this embodiment. Figure 8b is a perspective view of the suspension assembly 20a of this embodiment. Figure 8c is an exploded perspective view of the PZT motors, wire bond pad 84 for the top wire stitch connection 82, and conductive trace layer 44e showing details of the conductive epoxy pads 86 and trace pads 88 for mechanically bonding and electrically connecting to the PZT motors 22, 24.

In this embodiment, the PZT motors are mechanically and electrically bonded to trace pads 88 (or conductive pads), preferably made of gold plated copper on a flexure on the disk side of the suspension. The flexure 40a is made up of a stainless steel substrate 38a, a dielectric layer 42a (preferably of polyimide), and a conductive trace layer 43 containing conductive traces 44e (preferably of copper). The mechanical and electrical bonding is accomplished simultaneously using a conventional conductive epoxy adhesive to electrically connect one side (the bottom) of the PZT to the trace pads 88. In this embodiment, all four trace pads are at the same electrical potential. The remaining (top) electrical connection to the PZT is completed using the wire bond pad 84 in the conductive trace layer 43 electrically connected to an ultrasonically bonded gold wire (top wire stitch connection or “wire bond”) on the disk side of the suspension. It is to be understood that each PZT is otherwise electrically isolated from the stainless steel substrate (and load beam) by the dielectric layer 42a, as may be seen in Figure 8a. More particularly, dielectric layer 42a has insulating pads 90 interposed between copper pads 88 and areas 92 of the stainless steel flexure substrate 38a. Figure 8d illustrates the electrical layout of the wire bond pad 84 and trace pads 88 and connections 94 to individual traces in the conductive trace layer 43.

It is to be understood to be within the scope of the present invention to provide an assembly having only one PZT motor. Furthermore, it is within the present invention to use ultrasonic bonding of conductive leads formed from the flexure material as shown in Figures 8e-8i or to use ultrasonic bonding of conductive leads formed from an additional add-on component as shown in Figures 8j-8n to make the electrical connection to the PZT motor. Additionally, it is within the present

invention to use conductive epoxy or solder as shown in Figures 8o-8s to attach conductive leads formed from the flexure material or from an additional add-on component shown in Figures 8t-8x to make the electrical connection to the PZT motor. The versions shown in Figures 8e through 8x each have the PZT motors 22, 24 mounted on the disk side of the suspension, as were shown in Figures 5-8d.

In the version shown in Figures 8e – 8i, electrical connection is made to the surface 28 of the PZTs 22 and 24 in a manner similar to that shown in the previous version using trace pads 88 insulated from the stainless steel layer 38b by insulating pads 90a, except that ultrasonic bonding is used, as was done with respect to the version shown in Figures 4d-4h. A lead extension 96 is used to make electrical connection to the free side 26 of the PZTs 22 and 24, again using ultrasonic bonding. As may be seen most clearly in Figure 8i, the lead extension 96 has its laminate “inverted” by being folded over, such that the conductive trace 98 is facing and abutting side 26 of the PZTs, while being insulated by layer 99 and supported by the stainless steel layer 100.

Referring now most particularly to Figures 8j – 8n, another version of the present invention may be seen in which one separate piece is used to connect the leads in the flexure to the free side 26 of the PZTs. In this version, a separate piece 102 is formed of the same laminate as the flexure material may be used to connect leads 44 to the PZTs 22 and 24. Figures 8kk, 8kkk, and 8kkkk show a trace layer 104, a dielectric layer 106, and a stainless steel layer 108 useful in the practice of this version. Figures 8nn and 8nnn show, respectively, the separate piece 102 in plan view, and the various layers in a separated or exploded view. Layer 110 is a conductive trace layer, layer 112 is a dielectric layer, and layer 114 is a substrate which may be formed of stainless steel.

Referring now to Figures 8o through 8s, a version of the present invention may be seen in which the PZT motors are electrically and mechanically connected to extensions of the conductive traces by solder connections 116. In this version, the free side 26 of the PZTs 22 and 24 is connected to an extension 118, and the other

side 28 of the PZTs is connected to trace pads 120 forming part of a trace extension 122 similar to that shown in Figure 8kk.

In Figures 8t through 8x, a version using solder connections 116 with a separate piece 124 to connect to side 26 of the PZTs may be seen. Figure 8xx shows the various layers of the separate piece 124, and also shows a plan view of the laminated separate piece 124. Piece 124 includes a conductor layer 126 (which may be formed of copper or a copper alloy), a dielectric layer 128 (which may be formed of polyimide), and a substrate layer 130, (which may be formed of stainless steel). The trace pads and extension shown in Figure 8kk (or a similar arrangement) may be used to connect to side 28 of the PZT motors 22 and 24.

Referring now to Figures 9-12b, a third wire stitch alternative embodiment of the present invention with PZT motors 22, 24 mounted on the non-disk side of the suspension 20b may be seen. Figures 9 and 10 show the top and bottom plan views of this embodiment, and Figure 11 is an enlarged fragmentary view of a portion of Figure 9 showing details of the mounting arrangement for the PZT motors 22, 24 in this embodiment, but without showing the wire bond 82. Figure 12 is a still further enlarged section view taken along line 12-12 of Figure 11. Figure 12a is an exploded perspective view of the suspension assembly 20b of Figure 9, showing the PZT motors 22,24, the wire connection 82, the load beam 30c with apertures 132, a flexure metal substrate 134 with apertures 136, a dielectric layer 138 with apertures 140, a plurality of controlled amounts 142 of conductive epoxy, a conductive trace and pad layer 144 having a plurality of conductive pads 146 and a wire bond pad 148, and a mounting plate 50. As may be seen most clearly with respect to Figure 12a, the surface 28 of each of the PZT motors 22, 24 is mechanically mounted on the conductive pads 146 in the conductive trace layer 144 using a discrete amount of conductive epoxy 142, thus also providing an electrical connection to the surface 28 of the PZT motors 22 and 24. The mechanical and electrical connection is enabled by the apertures 132, 136, 140 aligned with the PZT motors in each of the load beam 30c, flexure metal substrate 134, and dielectric layer 138. The wire bond 82 makes an electrical connection between the wire bond pad 148 in the conductive layer 144 and

the surface 26 of the PZT motors 22 and 24. Figure 12b is a perspective view of the suspension assembly 20b of this embodiment. As may be most clearly seen in Figure 12, the mechanical connection between the PZT motors and the load beam is via the respective overlaps between the conductive pads 146, the dielectric layer 138 and the metal substrate 134 of the flexure, it being understood that in this embodiment the flexure 40 is made up of at least the flexure metal substrate 134, the dielectric (insulating) layer 138 and the conductive trace layer 144. It may thus be seen that the force developed by the PZT's is transferred first via conductive epoxy 142 to the conductive pads 146, and then through the dielectric layer 138 to the flexure metal substrate 134. The force is then transferred from the metal substrate 134 to the load beam 30c via a plurality of 6 laser welds, indicated by the asterisks ("*") 150 in Figure 10.

This embodiment is similar to the previous (second) wire stitch embodiment with the PZT motors 22, 24 bonded to pads 146 (which may be gold plated copper) on the flexure 40 except on the non-disk side of the suspension. The PZT motors 22 and 24 are each placed through appropriately sized apertures 132, 136 and 140 in the load beam and the flexure substrate and dielectric layers before being bonded to the pads 146 of the conductive trace layer 144. The bonding is accomplished using a conventional conductive adhesive 142. As has been described, the remaining electrical connection to the PZT is completed using an ultrasonically bonded wire 82 (which may be gold) on the non-disk side of the suspension. As may be seen most clearly in Figures 12 and 12b, this concept also has the benefit of bringing the motors more "in-plane" with the structure (i.e., into closer alignment with the primary plane 83 of the overall suspension assembly) to minimize gram share (the amount of gram load carried by each individual PZT).

It is to be understood to be within the scope of the present invention to provide an assembly having only one PZT motor. Furthermore, it is within the present invention to use ultrasonic bonding of conductive leads formed as extensions from the flexure material as shown in Figures 12c-12g or to use ultrasonic bonding of conductive leads formed from an additional add-on component as shown in Figures

12h-12l to make the electrical connection to the PZT motor. Additionally, it is within the present invention to use conductive epoxy or solder as shown in Figures 12m-12q to attach conductive leads formed from the flexure material or from an additional add-on component shown in Figures 12r-12v to make the electrical connection to the PZT motor.

Referring now most particularly to Figures 12c through 12g, a version similar to the third wire stitch version of the present invention may be seen in which a lead extension 152 replaces the wire bond or stitch 82. Lead extension 152 is a part of the flexure 40 and the conductive trace 154 in extension 152 is ultrasonically bonded to the PZTs 22, 24.

Referring now to Figures 12h – 12l, another version in which ultrasonic bonding is used with a separate piece of material 156 to form the connection to surface 26 of the PZTs 22 and 24. The separate piece 156 is formed of a laminate of a conductive layer 158, a dielectric layer 160, and a stainless steel substrate layer 162.

In Figures 12m through 12q, a version using solder to connect the PZTs with a lead extension 164 may be seen. Lead extension 164 is formed of the three layer laminate of flexure 40, including a conductive layer 166, a dielectric layer 168, and a supporting substrate 170 of stainless steel.

Referring now to Figures 12r through 12v, a version similar to that of Figures 12h-12l may be seen in which a separate piece 172 is used similar to 156, except that there are enlarged circular pads 174 in the conductive layer 158 to allow attachment using solder or conductive epoxy.

Referring now to Figures 13-18, a fourth alternative embodiment of the wire stitch version of the present invention may be seen. This embodiment has a prefabricated PZT motor subassembly 180 mounted on and forming part of the head suspension assembly. Figures 13 and 14 show the top and bottom plan views of this embodiment, and Figure 15 is an enlarged fragmentary view of a portion of Figure 13 showing details of the mounting arrangement for the PZT motors 22, 24 in this embodiment, except omitting the wire bonds. Figure 16 is an enlarged section view taken along line 16-16 of Figure 15 and showing the wire bond to the PZTs. In this

embodiment the pre-fabricated motor subassembly has PZT motors 22 and 24 already attached to conductive pads 182 similar to pads 146 and which are connected to a separate termination pad 184 on the motor subassembly 180. The PZT motor subassembly 180 includes the PZT elements 22 and 24, a motor conductive pad layer 186 with the motor termination pad 184 connected to the conductive pads 182 (for connection to the bottom surface 28 of the PZT elements 22, 24), a motor insulator layer 188, and a motor metal substrate layer 190. The motor subassembly 180 is preferably assembled first, and then installed (preferably by weld attachment at weld points 192 [indicated by the asterisks “*” in Figure 14] to the load beam 30d of the suspension). Alternatively, the motor subassembly 180 may be attached to the load beam 30d by adhesive. After the motor subassembly is mechanically or structurally attached to the suspension, a first ultrasonic wire bond 194 is completed from the first wire bond pad 196 in the conductive trace layer 198 of the suspension flexure 200 to the motor subassembly termination pad 184, and a second ultrasonic wire bond 202 is completed from the second wire bond pad 204 to the top surface 26 of both PZT motors 22 and 24 to complete the electrical connections to the motor subassembly 180. Figures 17 and 18 show, respectively, an exploded view and a perspective assembly view of the prefabricated motor subassembly and head suspension assembly to which it is attached. This version has a flexure substrate 206, a dielectric layer 208, and a conductive trace layer 210. Conductive epoxy 212 is used to bond the surface 28 of the PZTs 22 and 24 to the motor conductive pads 182.

It is within the present invention to have a separate motor subassembly which uses ultrasonic bonding of conductive leads formed from the flexure material as shown in Figures 18a-18e or to use ultrasonic bonding of conductive leads formed from an additional add-on component as shown in Figures 18f-18j to make the electrical connection to the PZT motor. Additionally, it is within the present invention to use conductive epoxy or solder as shown in Figures 18k-18o to attach conductive leads formed from the flexure material or from an additional add-on component shown in Figures 18p-18t to make the electrical connection to the PZT

motor in a separate subassembly similar to subassembly 180 used with the wire stitch attachment described previously.

Referring now most particularly to Figures 18a through 18e, a version of the present invention using a motor subassembly 220 may be seen. Figure 18cc shows an enlarged plan view of a metal substrate layer 222 useful for the motor subassembly 220. Figure 18ccc is a plan view of a dielectric layer 224 for the motor subassembly 220, and Figure 18cccc shows a conductive pad layer 226 for the motor subassembly 220. Figure 18dd shows the motor subassembly 220 and Figure 18ddd shows the motor subassembly with lead extensions 228 and 230, along with portions of the dielectric layer 232 of the flexure to connect to the PZTs 22 and 24 in the motor subassembly 220. In this embodiment, the lead extensions 228 is ultrasonically bonded to the surface 26 of the PZTs 22, 24 and the lead extension 230 is ultrasonically bonded to a bond pad 234 in the conductive pad layer 226 which is mechanically and electrically bonded to surface 28 of the PZTs 22 and 24.

Figures 18f – 18j illustrate another variation of the present invention wherein the motor subassembly 240 has a substrate 242, a dielectric layer 244 and a conductive pad layer 246 connected to surface 28 of PZTs 22 and 24. A first separate laminate piece 248 connects via ultrasonic bonding a first flexure bond pad 250 the surface 26 of PZTs, and a second separate laminate piece 252 connects via ultrasonic bonding between a second flexure bond pad 254 and a conductive pad layer bond pad 256.

Similarly, referring now to Figures 18k through 18o, lead extensions may be used to provide solder or conductive epoxy connections to the motor subassembly 260 in this version of the present invention. Motor subassembly 260 has a substrate layer 262, a dielectric layer 264, and a conductive pad layer 266 which carries a conductive pad layer bond pad 268. Solder or conductive epoxy connections at 270 and 272 connect a first lead extension 274 from flexure 40 to the surface 26 of PZTs 22 and 24, and solder or conductive epoxy connection 276 connects a second lead extension 278 to the bond pad 268. The load beam 30d for this version carries the motor

subassembly and may make use of the assembly details described with respect to Figures 13-18.

Referring now to Figures 18p through 18t, a version of the present invention may be seen in which two separate laminate pieces 280, 282 are used to connect to motor subassembly 260. In the view shown in Figure 18rr, the PZTs have been omitted, along with the stainless steel layer 38 of flexure 40, and apertures 284 in the portion of dielectric layer 42 are shown for the first and second flexure bond pads 250 and 254 of the conductive layer 43 of the flexure 40. Solder connections 286 and 288 may be used to connect separate pieces 280 and 282 as shown.

It is to be understood that in any of the above embodiments or versions using solder, that conductive epoxy may be used in place of the solder, while still remaining within the scope of the present invention.

Currently the chip set required to provide for both large positive and negative voltages (on the order of ± 30 volts) with respect to circuit common to drive the PZT motors with a bipolar source cannot be incorporated into the other driver electronics. This increases the cost of the hard drive by requiring that the drive circuit provide both +V and -V outputs with respect to circuit common. The present invention allows the hard drive controller to operate in a lower overall (although still bipolar) voltage range while maintaining the same stroke performance of the suspension, by dissociating the PZT's from circuit common so that either major surface of the PZT motors can be connected to either the drive output or circuit common. With this invention, the driver electronics can be incorporated into a single chip, decreasing component costs at the hard drive level.

The present invention may thus be seen to be apparatus and method for selectively applying a voltage to one of a first and a second major surface of at least one of a pair of piezoelectric motors (PZTs) on a disk drive head suspension with a primary plane of a load beam of the head suspension parallel to the major surfaces of the PZT elements, wherein the PZT elements are electrically insulated from the load beam. Electrical connection to the PZTs may be made via wires or electro-mechanical attachment of a plated surface of the PZT with a bond pad on an

electrically isolated substrate. The PZTs may be located on a first or second major surface of the load beam, or may be assembled in a pre-fabricated motor assembly before being installed in the head suspension. Apertures in the load beam and other layers permit physical installation of the PZT motors and enable electrical connection to a side of the PZTs that would otherwise be substantially inaccessible for such electrical connection.

This invention is not to be taken as limited to all of the details thereof as modifications and variations thereof may be made without departing from the spirit or scope of the invention. For example, and not by way of limitation, the structure or technique shown or described with respect to one version or embodiment may be used with other versions or embodiments where desired. By way of another example, and not by way of limitation, the separate piece used in various embodiments described above may be an isolated conductor while still remaining within the spirit and scope of the present invention. Such an isolated conductor may have an aspect ratio of width to thickness of about five to one or greater. Furthermore, such a separate piece may be formed generally in the z-axis direction (i.e., generally perpendicular to the plane of the suspension or the plane of one of the major surfaces 26 or 28 of the PZTs) as desired to conform to the pad and PZT topography. The isolated conductor may be attached via ultrasonic bonding, solder or conductive epoxy.